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Assessment of Green Supplier Development Programs by a New Group Decision-Making Model Considering Possibilistic Statistical Uncertainty

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Abstract- *The assessment and selection of green supplier development programs are an intriguing and functional research subject. This paper proposes a group decision-making approach considering possibilistic statistical concepts under uncertainty to assess green supplier development programs (GSDPs) via interval-valued fuzzy sets (IVFSs). Possibility theory is employed to regard uncertainty by IVFSs. A new version of a technique for order preference by similarity to ideal solution (TOPSIS) is proposed to solve the decision problem. Possibilistic mean, standard deviation, and cube-root of skewness matrices are provided to consider relative closeness coefficients. In addition, a new version of an entropy method is introduced to obtain criteria weights under uncertainty. Finally, an illustrative example in an automobile manufacturing system is given to show the capability of the presented approach in addition to comparisons with recent fuzzy decision techniques for GSDPs.*

Keywords*: Green supplier development, multi-attributes analysis, possibilistic statistical concepts, interval-valued fuzzy sets.*

I. INTRODUCTION

Supply chain management (SCM) is viewed as a technique that deals with this affix adequately to fulfill client prerequisites (Beamon, 1998); (Chauhan et al., 2004); (Santoso et al., 2005). Likewise, environmental administration can be portrayed as the organization of human's communications with environmental and their belongings (Nikbakhsh, 2009); (Lee et al., 2011).

Improving the environmental execution of suppliers is fundamental in developing green supply chains. Suppliers being the first and preeminent imperative connection in any association rehearse a wonderful control in developing green inventory network execution by noteworthy raw materials (Min & Galle, 2001); (Tate et al., 2012). Environmental execution appraisal of providers is the primary stage in green supplier development. Suppliers who rank low in environmental execution would benefit from outside intervention through various green supplier progression ventures (Awasthi & Kannan, 2016).

(Bai & Sarkis 2010) displayed a formal model by using a rough set theory to analyze the associations between hierarchical properties, supplier development program inclusion characteristics, and execution results. (Fu et al. 2012) built up a formal organized administrative methodology for associations for surveying the impact connections among green supplier development programs (GSDPs). (Blome et al. 2014) got contradicting hypothetical perspectives of authenticity in evaluating firm execution and best administration duty as aftereffects of green supplier development. (Dou et al. 2014) considered a grey-based model to choose with respect to GSDPs that would feasibly develop suppliers' natural execution in a principle producer in China.

(Akman 2015) decided green execution of supplier and characterized which suppliers expected to enhance their conditions in regards to ecological issues and which suppliers ought to be incorporated into GSDPs to improve their

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environmental execution. (Awasthi and Kannan 2016) assessed supplier development programs and suggested a fuzzy NGT-VIKOR (Nominal Group Technique - VlseKriterijumska Optimizacija I Kompromisno Resenje) based arrangement approach.

(Qin et al. 2017) developed the TODIM technique for solving MCGDM problems in view of an interval type-2 fuzzy sets (IT2FSs) and showed the usage in a green supplier selection problem. (Glock et al. 2017) surveyed all decision support models for developing suppliers to find the principled literature review that distinguished promising areas for future research around areas.

(Luthra et al. 2017) introduced a structure to assess sustainable supplier selection by utilizing an incorporated AHP, VIKOR, a multi-criteria optimization, and compromise solution procedures. Additionally, a case of a car organization in India is talked about. (Tian et al. 2018) proposed multi-criteria based leadership approach coordinating with AHP, grey relationship, and TOPSIS to choose the ideal green decoration materials for a situation investigation of strong woods.

The above-mentioned literature on the GSDPs shows that an appraisal of the problem can be a multi-criteria group decision-making (MCGDM) framework in SCNs, and it is regarded as a new research area. In practice, several evaluation factors or criteria can influence this selection issue under uncertain conditions.

Main research questions addressed in this research that indicate its importance and necessity are as follows:

- Which criteria should be used for assessment of GSDPs?
- How can one handle uncertainty and asymmetric information in these types of decision-making problems?

In this paper, an assessment procedure for GSDPs is presented with a new fuzzy group decision-making approach with possibilistic statistical concepts (PSCs) based on TOPSIS under an interval-valued fuzzy set (IVFS). In addition, a new version of an entropy method is developed for calculating weights of assessment factors by PSCs. New closeness coefficients of alternative indices are presented to give an order of GSDPs with IVFS.

The rest of this study is presented below. The research background and presented approach are given in Sections II and III. Section IV provides the illustrative example and the computational process. Finally, conclusions are given in Section V.

II. PRELIMINARIES

A. IVFNS

The fuzzy numbers can contain trapezoidal IVFNs, triangular shape, and interval-valued triangular fuzzy numbers. A graphical representation of an IVFN is depicted in Fig (1). Triangular IVFN is denoted by (Yao & Lin, 2002):

$$\tilde{F} = \left[\underline{\tilde{f}}, \tilde{\tilde{f}}\right] = \left[\left(\underline{f}_1, \underline{f}_2, \underline{f}_3; \hat{h}_{\underline{\tilde{F}}}\right), \left(\overline{f}_1, \overline{f}_2, \overline{f}_3; \hat{\hat{h}}_{\tilde{F}}\right)\right] \tag{1}$$

$\underline{\tilde{F}}$ and $\tilde{\tilde{F}}$ denoted as two TFNs; hence, $\hat{h}_{\underline{\tilde{f}}}$ and $\hat{\hat{h}}_{\tilde{A}}$ show their heights, and $\underline{f}_1, \underline{f}_2, \underline{f}_3, \overline{f}_1, \overline{f}_2, \overline{f}_3$ regard real values; $0 \leq \underline{f}_1 \leq \underline{f}_2 \leq \underline{f}_3 \leq 1$, $0 \leq \overline{f}_1 \leq \overline{f}_2 \leq \overline{f}_3 \leq 1$, $\overline{f}_1 \leq \underline{f}_1$, and $\underline{f}_3 \leq \overline{f}_3$.

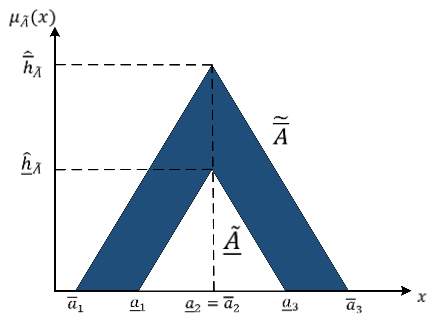

Fig 1. Interval-valued fuzzy number

B. The possibility theory

$\tilde{F} \in x$ show fuzzy number by $[\tilde{F}]^{\gamma} = [f_1(\gamma), f_2(\gamma)], \gamma \in [0,1]$. Possibilistic mean (PM) estimation of fuzzy number $\tilde{F}$ can be characterized as $M(\tilde{F}) = \int_0^1 \gamma(f_1(\gamma) + f_2(\gamma))$, and possibilistic difference of $\tilde{A}$ as $Var(\tilde{F}) = \frac{1}{2}\int_0^1 \gamma(f_1(\gamma) - a_2(\gamma))^2 d\gamma$ (Zhang et al., 2007; Ye and Lin, 2013; Deng and Li, 2014; Li et al., 2010).

PM estimation of TFN $\tilde{\xi} = (b, c, d)$ is as follows:

$$PM(\tilde{\xi}) = \int_0^1 \gamma\big((b - (1-\gamma)\tau) + (b + (1-\gamma)\sigma)\big)d\gamma = (b + 2c + d)/4 \tag{2}$$

Possibilistic variance (PV) of TFN $\tilde{\xi}$ is as follows:

$$PV(\tilde{\xi}) = \int_0^1 \gamma\big((b - (1-\gamma)\tau) + (b + (1-\gamma)\sigma)\big)^2 d\gamma = (33\alpha_1^3 + 21\alpha_1^2\gamma + 11\alpha_1\gamma^2 - \gamma^3)/384\alpha_1 \tag{3}$$

where $\alpha_1 = \max\{c - b, d - c\}$ and $\gamma = \min\{c - b, d - c\}$.

Possibilistic skewness (PS) of TFN $\tilde{\xi}$ is as follows:

$$\begin{aligned} PS(\tilde{\xi}) &= {}^{1}/_{8(c-b)}\left[\left({}^{(c-e)}/_{4}\right)^4 - \left({}^{(b-e)}/_{4}\right)^4\right] + {}^{1}/_{8(c-d)}\left[\left({}^{(c-e)}/_{4}\right)^4 - \left({}^{(d-e)}/_{4}\right)^4\right] \\ &= \left({}^{(d-b)^2}/_{32}\right)(d + b - 2c) \end{aligned} \tag{4}$$

It implies that if $\geq \tau$, then $Skew(\tilde{A}) \geq 0$ and if $\sigma \leq \tau$, then $Skew(\tilde{A}) \leq 0$. Especially, if $\tilde{A}$ is symmetric, then we have $\sigma = \tau$ and $Skew(\tilde{A}) = 0$. Furthermore, for fixed $a - \tau$ and a, if $a - \tau = a$, then $Skew(\tilde{A})$ obtains its maximum value $[(\sigma + \tau)^3/32)]$; and if $a = a + \sigma$, then $Skew(\tilde{A})$ obtains its minimum value $[-(\sigma + \tau)^3/32)]$.

III. PRESENTED FUZZY GROUP DECISION APPROACH

An assessment procedure for GSDPs is presented with a fuzzy group decision approach by PSCs under uncertainty. First, the following cases are considered:

$DM = \{DM^k | k = 1, \dots, p\}$ a set of DMs,

$X = \{X_i | i = 1, \dots, m\}$ as a set of GSDP candidates, and

$C = \{C_j | j = 1, \dots, n\}$ as a set of factors for the GSDP.

The GDM problem for the selection of the GSDP is given by:

$$\tilde{F}^k = \left[[(\underline{f}_{ij_1}, \underline{f}_{ij_2}, \underline{f}_{ij_3}), (\overline{f}_{ij_1}, \overline{f}_{ij_2}, \overline{f}_{ij_3})]^k\right]_{m\times n} = \begin{bmatrix} [(\underline{f}_{11_1}, \underline{f}_{11_2}, \underline{f}_{11_3}), (\overline{f}_{11_1}, \overline{f}_{11_2}, \overline{a}_{11_3})]^k & \cdots & [((\underline{f}_{1n_1}, \underline{f}_{1n_2}, \underline{f}_{1n_3}), (\overline{f}_{1n_1}, \overline{f}_{1n_2}, \overline{f}_{1n_3})]^k \\ \vdots & \ddots & \vdots \\ [((\underline{f}_{m1_1}, \underline{f}_{m1_2}, \underline{f}_{m1_3}), (\overline{f}_{m1_1}, \overline{f}_{m1_2}, \overline{f}_{m1_3})]^k & \cdots & [(\underline{f}_{mn_1}, \underline{f}_{mn_2}, \underline{f}_{mn_3}), (\overline{f}_{mn_1}, \overline{f}_{mn_2}, \overline{f}_{mn_3})]^k \end{bmatrix} \tag{5}$$

The steps of the presented approach are given below:

Step 1. Identify evaluation factors for the assessment problem of GSDPs.

Step 2. Determine IVF-decision matrices of GSDP candidates, and combine them by:

$$\underline{f}_{ijl} = \frac{1}{p}\sum_{k=1}^{p}(\underline{f}_{ij_l})^k \;; l = 1,2,3 \quad \text{and} \quad \overline{f}_{ijl} = \frac{1}{p}\sum_{k=1}^{p}(\overline{f}_{ij_l})^k \;; l = 1,2,3 \tag{6}$$

Step 3. Convert the aggregated IVF-matrix into the normalized matrix of GSDP candidates.

Step 4. Consider the PM-interval value matrix for the GSDP by:

$$\breve{pm}_{ij} = \left[\underline{pm}_{ij}, \overline{pm}_{ij}\right] = \left[\frac{\left(\underline{f}'_{ij_1} + 2 \times \underline{f}'_{ij_2} + \underline{f}'_{ij_3}\right)}{4}, \frac{\left(\overline{f}'_{ij_1} + 2 \times \overline{f}'_{ij_2} + \overline{f}'_{ij_3}\right)}{4}\right] \tag{7}$$

The PM-interval value matrix is given by:

$$\breve{PM} = \left[\breve{pm}_{ij}\right]_{m \times n} = \begin{bmatrix} \breve{pm}_{11} & \breve{pm}_{12} & \cdots & \breve{pm}_{3n} \\ \breve{pm}_{21} & \breve{pm}_{22} & \cdots & \breve{pm}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \breve{pm}_{m1} & \breve{pm}_{m2} & \cdots & \breve{pm}_{mn} \end{bmatrix} \tag{8}$$

Step 5. Consider the PSD-interval value matrix for GSDPs by:

$$\breve{PSD}_{ij} = \left[\underline{psd}_{ij}, \overline{psd}_{ij}\right] = \left[\sqrt[2]{\frac{33(\underline{\alpha})^3 + 21(\underline{\alpha})^2(\underline{\gamma}) + 11(\underline{\alpha})(\underline{\gamma})^2 - (\underline{\gamma})^3}{384(\underline{\alpha})}}, \sqrt[2]{\frac{33(\overline{\alpha})^3 + 21(\overline{\alpha})^2(\overline{\gamma}) + 11(\overline{\alpha})(\overline{\gamma})^2 - (\overline{\gamma})^3}{384(\overline{\alpha})}}\right] \tag{9}$$

where $\underline{\alpha} = \max\{\underline{\tau}'_{ij}, \underline{\sigma}'_{ij}\}$, $\underline{\gamma} = \min\{\underline{\tau}'_{ij}, \underline{\sigma}'_{ij}\}$, $\overline{\alpha} = \max\{\overline{\tau}'_{ij}, \overline{\sigma}'_{ij}\}$, and $\overline{\gamma} = \min\{\overline{\tau}'_{ij}, \overline{\sigma}'_{ij}\}$.

The PSD-interval value matrix is given by:

$$\breve{PSD} = \left[\breve{psd}_{ij}\right]_{m \times n} = \begin{bmatrix} \breve{psd}_{11} & \breve{psd}_{12} & \cdots & \breve{psd}_{3n} \\ \breve{psd}_{21} & \breve{psd}_{22} & \cdots & \breve{psd}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \breve{psd}_{m1} & \breve{psd}_{m2} & \cdots & \breve{psd}_{mn} \end{bmatrix} \tag{10}$$

Step 6. Consider the PCRS-interval value matrix for GSDPs by:

$$\breve{pcrs}_{ij} = \left[\underline{pcrs}_{ij}, \overline{pcrs}_{ij}\right] = \left[\sqrt[3]{\frac{\left(\underline{a}'_{ij_3} - \underline{a}'_{ij_1}\right)^2}{32}\left(\underline{a}'_{ij_3} + \underline{a}'_{ij_1} - 2 \times \underline{a}'_{ij_2}\right)}, \sqrt[3]{\frac{\left(\overline{a}'_{ij_3} - \overline{a}'_{ij_1}\right)^2}{32}\left(\overline{a}'_{ij_3} + \overline{a}'_{ij_1} - 2 \times \overline{a}'_{ij_2}\right)}\right] \tag{11}$$

The PCRS-interval value matrix is given by:

$$\breve{PCRS} = \left[\breve{pcrs}_{ij}\right]_{m \times n} = \begin{bmatrix} \breve{pcrs}_{11} & \breve{pcrs}_{12} & \cdots & \breve{pcrs}_{3n} \\ \breve{pcrs}_{21} & \breve{pcrs}_{22} & \cdots & \breve{pcrs}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \breve{pcrs}_{m1} & \breve{pcrs}_{m2} & \cdots & \breve{pcrs}_{mn} \end{bmatrix} \tag{12}$$

Step 7. Compute the entropy weighting method with PSCs for the GSDP.

Sub-step 7.1. Calculate the PM-entropy measure with interval values for each green supplier development evaluation criterion.

$$\breve{E}(pm)_j = \left[\underline{e}(pm)_j, \overline{e}(pm)_j\right] = \left[-\frac{1}{Ln(pm)}\sum_{i=1}^{m} \overline{pm}'_{ij} Ln\left(\overline{pm}'_{ij}\right), -\frac{1}{Ln(pm)}\sum_{i=1}^{m} \underline{pm}'_{ij} Ln\left(\underline{pm}'_{ij}\right)\right] \tag{13}$$

where $\breve{pm}'_{ij} = \left[\underline{pm}'_{ij}, \overline{pm}'_{ij}\right] = \left[\frac{\underline{pm}_{ij}}{\max_i \overline{pm}_{ij}}, \frac{\overline{pm}_{ij}}{\max_i \overline{pm}_{ij}}\right]$.

Sub-step 7.2. Calculate the PSD-entropy measure with interval values for each green supplier development evaluation criterion.

$$\breve{E}(psd)_j = \left[\underline{e}(psd)_j, \overline{e}(psd)_j\right] = \left[-\frac{1}{Ln(psd)}\sum_{i=1}^{m}\overline{psd'}_{ij}Ln\left(\overline{psd'}_{ij}\right), -\frac{1}{Ln(psd)}\sum_{i=1}^{m}\underline{psd'}_{ij}Ln\left(\underline{psd'}_{ij}\right)\right] \quad (14)$$

where $\overline{psd}'_{ij} = \left[\underline{psd'}_{ij}, \overline{psd'}_{ij}\right] = \left[\frac{\underline{psd}_{ij}}{max\ _i\overline{psd}_{ij}}, \frac{\overline{psd}_{ij}}{max\ _i\overline{psd}_{ij}}\right]$.

Sub-step 7.3. Calculate the PCRS-skewness entropy measure with interval values for each green supplier development evaluation criterion.

$$\breve{E}(pcrs)_j = \left[\underline{e}(pcrs)_j, \overline{e}(pcrs)_j\right] = \left[-\frac{1}{Ln(pcrs)}\sum_{i=1}^{m}\overline{pcrs'}_{ij}Ln\left(\overline{pcrs'}_{ij}\right), -\frac{1}{Ln(pcrs)}\sum_{i=1}^{m}\underline{pcrs'}_{ij}Ln\left(\underline{pcrs'}_{ij}\right)\right] \quad (15)$$

where $\overline{pcrs}'_{ij} = \left[\underline{pcrs'}_{ij}, \overline{pcrs'}_{ij}\right] = \left[\frac{\underline{pcrs}_{ij}}{max\ _i\overline{pcrs}_{ij}}, \frac{\overline{pcrs}_{ij}}{max\ _i\overline{pcrs}_{ij}}\right]$.

Step 8. Calculate proposed final weights of green supplier development evaluation criteria with PSCs for the GSDP.

Sub-step 8.1. Consider the entropy weight by PM-interval values.

$$\breve{W}(pm)_j = \left[\underline{w}(pm)_j, \overline{w}(pm)_j\right] = \left[1 - \overline{e}(pm)_j, 1 - \underline{e}(pm)_j\right] \quad (16)$$

Sub-step 8.1. Consider the entropy weight by PSD-interval values.

$$\breve{W}(sd)_j = \left[\underline{w}(psd)_j, \overline{w}(psd)_j\right] = \left[1 - \overline{e}(psd)_j, 1 - \underline{e}(psd)_j\right] \quad (17)$$

Sub-step 8.1. Consider the entropy weight by PCRS-interval values.

$$\breve{W}(pcrs)_j = \left[\underline{w}(pcrs)_j, \overline{w}(pcrs)_j\right] = \left[1 - \overline{e}(pcrs)_j, 1 - \underline{e}(pcrs)_j\right] \quad (18)$$

Step 9. Regard positive-ideal and negative-ideal vectors (PIV &NIV) of PM for each GSDP by:

$$\widetilde{PM}^* = \left\{\widetilde{PM}_1^*, \widetilde{PM}_2^*, \dots, \widetilde{PM}_n^*\right\} = \left\{\left[\underline{pm}_j^*, \overline{pm}_j^*\right]\right\} = \left\{\max_i \widetilde{pm}_{ij} \middle| i = 1,2,\dots,m\right\} \quad (19)$$

$$\widetilde{PM}^- = \left\{\widetilde{PM}_1^-, \widetilde{PM}_2^-, \dots, \widetilde{PM}_n^-\right\} = \left\{\left[\underline{pm}_j^-, \overline{pm}_j^-\right]\right\} = \left\{\min_i \widetilde{pm}_{ij} \middle| i = 1,2,\dots,m\right\} \quad (20)$$

Step 10. Regard PIV and NIV of PSD by:

$$\widetilde{PSD}^* = \left\{\widetilde{PSD}_1^*, \widetilde{PSD}_2^*, \dots, \widetilde{PSD}_n^*\right\} = \left\{\left[\underline{psd}_j^*, \overline{psd}_j^*\right]\right\} = \left\{\min_i \widetilde{psd}_{ij} \middle| i = 1,2,\dots,m\right\} \quad (21)$$

and

$$\widetilde{PSD}^- = \left\{\widetilde{PSD}_1^-, \widetilde{PSD}_2^-, \dots, \widetilde{PSD}_n^-\right\} = \left\{\left[\underline{psd}_j^-, \overline{psd}_j^-\right]\right\} = \left\{\max_i \widetilde{psd}_{ij} \middle| i = 1,2,\dots,m\right\} \quad (22)$$

Step 11. Regard PIV and NIV of PCRS by:

$$\widetilde{PCRS}^* = \left\{\widetilde{PCRS}_1^*, \widetilde{PCRS}_2^*, \dots, \widetilde{PCRS}_n^*\right\} = \left\{\left[\underline{pcrs}_j^*, \overline{pcrs}_j^*\right]\right\} = \left\{\min_i \widetilde{pcrs}_{ij} \middle| i = 1,2,\dots,m\right\} \quad (23)$$

and

$$\widetilde{PCRS}^- = \left\{\widetilde{PCRS}_1^-, \widetilde{PCRS}_2^-, \dots, \widetilde{PCRS}_n^-\right\} = \left\{\left[\underline{pcrs}_j^-, \overline{pcrs}_j^-\right]\right\} = \left\{\max_i \widetilde{pcrs}_{ij} \middle| i = 1,2,\dots,m\right\} \quad (24)$$

Step 12. Regard the separation measure matrix of each GSDP with PSCs from the PIV ($\widetilde{PM}^*$, $\widetilde{PSD}^*$, $\widetilde{PCRS}^*$).

The separation vectors are as follows:

$$pm_{D_{ij}^*}\left(\widetilde{pm}_{ij}, \widetilde{PM}_j^*\right) = \sqrt{\sum_{j=1}^{n}\left(\underline{w}(pm)_j\left(\underline{m}_j^* - \underline{m}_{ij}\right)^2 + \overline{w}(m)_j\left(\overline{m}_j^* - \overline{m}_{ij}\right)^2\right)} \quad (25)$$

$$psd_{D_{ij}^{*}}\left(\widetilde{psd}_{ij},\widetilde{PSD}_{j}^{*}\right)=\sqrt{\sum_{j=1}^{n}\left(\underline{w}(psd)_{j}\left(\underline{sd}_{j}^{*}-\underline{sd}_{ij}\right)^{2}+\overline{w}(psd)_{j}(\overline{psd}_{j}^{*}-\overline{psd}_{ij})^{2}\right)} \tag{26}$$

and

$$pcrs_{D_{ij}^{*}}\left(\widetilde{pcrs}_{ij},\widetilde{PCRS}_{j}^{*}\right)=\sqrt{\sum_{j=1}^{n}\left(\underline{w}(pcrs)_{j}\left(\underline{pcrs}_{j}^{*}-\underline{pcrs}_{ij}\right)^{2}+\overline{w}(pcrs)_{j}(\overline{pcrs}_{j}^{*}-\overline{pcrs}_{ij})^{2}\right)} \tag{27}$$

Step 13. Consider the separation measure matrix of each GSDP candidate by the PM, PSD, and PCRS from the NIV ($\widetilde{M}^{-}$, $\widetilde{SD}^{-}$, $\widetilde{CRS}^{-}$).

Separation vectors are as follows:

$$pm_{D_{ij}^{-}}\left(\widetilde{pm}_{ij},\widetilde{PM}_{j}^{-}\right)=\sqrt{\sum_{j=1}^{n}\left(\underline{w}(pm)_{j}\left(\underline{pm}_{j}^{-}-\underline{pm}_{ij}\right)^{2}+\overline{w}(pm)_{j}\left(\overline{pm}_{j}^{-}-\overline{pm}_{ij}\right)^{2}\right)} \tag{28}$$

$$psd_{D_{ij}^{-}}\left(\widetilde{psd}_{ij},\widetilde{PSD}_{j}^{-}\right)=\sqrt{\sum_{j=1}^{n}\left(\underline{w}(psd)_{j}\left(\underline{psd}_{j}^{-}-\underline{psd}_{ij}\right)^{2}+\overline{w}(psd)_{j}(\overline{psd}_{j}^{-}-\overline{psd}_{ij})^{2}\right)} \tag{29}$$

and

$$crs_{D_{ij}^{-}}\left(\widetilde{crs}_{ij},\widetilde{CRS}_{j}^{-}\right)=\sqrt{\sum_{j=1}^{n}\left(\underline{w}(pcrs)_{j}\left(\underline{pcrs}_{j}^{-}-\underline{pcrs}_{ij}\right)^{2}+\overline{w}(pcrs)_{j}(\overline{pcrs}_{j}^{-}-\overline{pcrs}_{ij})^{2}\right)} \tag{30}$$

Step 14. Calculate closeness coefficients of GSDPs X_i for PM, PSD, and PCRS by:

$$\Gamma_i=\frac{pm_{D_{ij}^{-}}\left(\widetilde{pm}_{ij},\widetilde{PM}_{j}^{-}\right)}{pm_{D_{ij}^{-}}\left(\widetilde{pm}_{ij},\widetilde{PM}_{j}^{-}\right)+pm_{D_{ij}^{*}}\left(\widetilde{pm}_{ij},\widetilde{PM}_{j}^{*}\right)} \tag{31}$$

$$K_i=\frac{sd_{D_{ij}^{-}}\left(\widetilde{sd}_{ij},\widetilde{SD}_{j}^{-}\right)}{psd_{D_{ij}^{-}}\left(\widetilde{psd}_{ij},\widetilde{PSD}_{j}^{-}\right)+sd_{D_{ij}^{*}}\left(\widetilde{psd}_{ij},\widetilde{PSD}_{j}^{*}\right)} \tag{32}$$

and

$$Z_i=\frac{pcrs_{D_{ij}^{-}}\left(\widetilde{pcrs}_{ij},\widetilde{PCRS}_{j}^{-}\right)}{pcrs_{D_{ij}^{-}}\left(\widetilde{pcrs}_{ij},\widetilde{PCRS}_{j}^{-}\right)+crs_{D_{ij}^{*}}\left(\widetilde{pcrs}_{ij},\widetilde{PCRS}_{j}^{*}\right)} \tag{33}$$

Step 15. Calculated the proposed final score using a linear combination of closeness coefficients of GSDP X_i.

$$Sc_i=\alpha\Gamma_i+\beta K_i+\varepsilon Z_i, \tag{34}$$

where $\sum \alpha+\beta+\varepsilon=1$, $0\le\alpha\le1$, $0\le\beta\le1$ and $0\le\varepsilon\le1$.

Step 16. Appraise the order of GSDPs by their coefficients, and choose the best candidate.

IV. ILLUSTRATIVE EXAMPLE

In this section, an automobile manufacturing organization is considered from the literature located in India (Awasthi & Kannan, 2016). This organization regards three GSDPs, including mandatory ISO 14000 certification (P_1), supplier training (P_2), and employee deployment with environment expertise at supplier locations (P_3). A group of three decision makers (i.e., DM_1, DM_2, & DM_3) is considered for the appraisement. DM_1 and DM_3 are pessimistic and DM_3 is moderate.

The committee applies the following criteria in the GSDPs assessment:

- Time (C_1),
- Cost (C_2),
- Labor (C_3),
- Resources (C_4),
- Energy Usage (C_5),
- Water (C_6),
- Emissions (C_7),
- Noise (C_8),
- Waste (C_9),
- Green packaging (C_{10}),
- Green manufacturing (C_{11}),
- Green product design (C_{12}),
- Green transportation (C_{13}),
- Green warehousing (C_{14}),
- Green procurement (C_{15}),
- Reverse logistics (C_{16}).

Linguistic terms are presented in Table I for the computations. Table II provides the linguistic ratings for the criteria. The computational results are represented in Tables III and IV according to the procedure of GSDPs with a new fuzzy group decision-making model by PSCs under uncertainty.

TABLE I. Linguistic variables for the values of GSDPs

Linguistic Variables	**Interval-valued Fuzzy Numbers**
Very Poor (VP)	[(0.00,0.00,2.00), (0.00,0.00,3.50)]
Poor (P)	[(1.00,2.50,4.00), (0.00,2.50,6.00)]
Fair (F)	[(3.50,5.00,6.50), (2.00,5.00,8.00)]
Good (G)	[(6.00,7.50,9.00), (4.00,7.50,10.00)]
Very Good (VG)	[(8.00,10.00,10.00), (6.50,10.00,10.00)]

TABLE II. Linguistic assessments for three alternatives of GSDPs

Criteria	P_1			P_2			P_3		
	DM_1	DM_2	DM_3	DM_1	DM_2	DM_3	DM_1	DM_2	DM_3
C_1	P	P	VG	VP	VG	VP	G	G	P
C_2	VP	P	VP	VP	VP	F	G	P	VP
C_3	G	VG	VP	VG	VG	F	VG	G	VP
C_4	P	VP	VG	VP	VP	F	G	G	VP
C_5	F	G	P	G	F	F	P	VG	P
C_6	VG	P	VG	F	F	F	P	F	P
C_7	VP	F	F	G	P	G	F	F	F
C_8	F	VG	VG	F	F	VP	F	VP	P
C_9	VP	G	G	G	VP	VP	F	VG	P
C_{10}	G	F	F	G	P	VG	G	F	P
C_{11}	G	VP	VG	VG	G	P	P	VG	VP
C_{12}	VP	F	VG	VP	VP	VP	G	VP	F
C_{13}	P	G	F	VG	VG	F	P	VG	VG
C_{14}	VP	P	P	VP	VP	F	F	VG	F
C_{15}	VG	P	G	VP	G	F	P	G	VG
C_{16}	G	G	G	P	F	F	F	VP	F

TABLE IV. Computational process for the presented decision approach

Criteria	$\widetilde{PM} = [\widetilde{pm}_{ij}]_{m\times n}$			$\widetilde{PSD} = [\widetilde{psd}_{ij}]_{m\times n}$			$\widetilde{PCRS} = [\widetilde{pcrs}_{ij}]_{m\times n}$		
	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3
C_1	[0.58,0.63]	[0.66,0.74]	[0.41,0.47]	[0.09,0.16]	[0.07,0.13]	[0.10,0.20]	[0.09,0.17]	[0.08,0.14]	[0.11,0.22]
C_2	[0.73,0.82]	[0.67,0.74]	[0.54,0.59]	[0.06,0.10]	[0.06,0.10]	[0.07,0.13]	[0.06,0.11]	[0.06,0.11]	[0.07,0.13]
C_3	[0.50,0.55]	[0.27,0.27]	[0.56,0.59]	[0.11,0.20]	[0.11,0.20]	[0.09,0.17]	[0.11,0.21]	[0.11,0.21]	[0.09,0.18]
C_4	[0.55,0.60]	[0.71,0.79]	[0.42,0.46]	[0.11,0.20]	[0.11,0.20]	[0.07,0.14]	[0.06,0.11]	[0.06,0.11]	[0.08,0.15]
C_5	[0.45,0.52]	[0.38,0.42]	[0.69,0.76]	[0.09,0.18]	[0.09,0.18]	[0.06,0.12]	[0.10,0.20]	[0.10,0.19]	[0.06,0.12]
C_6	[0.35,0.38]	[0.50,0.56]	[0.49,0.58]	[0.07,0.13]	[0.10,0.20]	[0.10,0.19]	[0.08,0.13]	[0.10,0.21]	[0.10,0.20]
C_7	[0.61,0.68]	[0.39,0.42]	[0.46,0.52]	[0.08,0.15]	[0.09,0.18]	[0.09,0.18]	[0.08,0.16]	[0.10,0.19]	[0.10,0.19]
C_8	[0.20,0.20]	[0.61,0.68]	[0.52,0.55]	[0.08,0.15]	[0.08,0.15]	[0.06,0.12]	[0.06,0.16]	[0.08,0.16]	[0.06,0.12]
C_9	[0.45,0.49]	[0.69,0.76]	[0.38,0.44]	[0.08,0.16]	[0.06,0.12]	[0.09,0.17]	[0.08,0.16]	[0.06,0.12]	[0.10,0.19]
C_{10}	[0.54,0.62]	[0.60,0.68]	[0.46,0.52]	[0.09,0.18]	[0.08,0.16]	[0.09,0.18]	[0.10,0.19]	[0.08,0.16]	[0.10,0.19]
C_{11}	[0.53,0.61]	[0.62,0.68]	[0.44,0.45]	[0.08,0.15]	[0.08,0.15]	[0.06,0.12]	[0.08,0.16]	[0.08,0.15]	[0.06,0.12]
C_{12}	[0.62,0.65]	[0.07,0.12]	[0.46,0.53]	[0.08,0.15]	[0.08,0.14]	[0.11,0.21]	[0.09,0.15]	[0.09,0.15]	[0.12,0.23]
C_{13}	[0.44,0.48]	[0.71,0.79]	[0.64,0.71]	[0.08,0.16]	[0.06,0.11]	[0.06,0.11]	[0.09,0.17]	[0.06,0.11]	[0.06,0.11]
C_{14}	[0.18,0.20]	[0.20,0.20]	[0.62,0.69]	[0.08,0.16]	[0.08,0.15]	[0.08,0.15]	[0.08,0.16]	[0.08,0.16]	[0.08,0.15]
C_{15}	[0.67,0.68]	[0.45,0.47]	[0.62,0.68]	[0.08,0.13]	[0.08,0.15]	[0.08,0.15]	[0.08,0.11]	[0.08,0.15]	[0.08,0.15]
C_{16}	[0.61,0.70]	[0.33,0.37]	[0.26,0.30]	[0.08,0.15]	[0.08,0.16]	[0.08,0.15]	[0.08,0.16]	[0.08,0.17]	[0.08,0.16]

The final weights of the green supplier development evaluation criteria by PSCs are calculated for assessments of GSDPs as follows:

$\breve{W}(pm)_j = [\underline{w}(pm)_j, \overline{w}(pm)_j]$
$= [(0.43,0.60), (0.51,0.71), (0.51,0.62), (0.37,0.52), (0.33,0.47), (0.48,0.71), (0.38,0.54),$
$(0.39,0.51), (0.32,0.46), (0.49,0.73), (0.48,0.65), (0.51,0.57), (0.46,0.63),$
$(0.26,0.35), (0.65,0.77), (0.23,0.36)]$

$\breve{W}(psd)_j = [\underline{w}(psd)_j, \overline{w}(psd)_j]$
$= [(0.02,0.59), (0.04,0.69), (0.07,0.89), (0.02,0.64), (0.03,0.73), (0.03,0.73), (0.04,0.85),$
$(0.05,0.80), (0.03,0.68), (0.04,0.89), (0.06,0.83), (0.02,0.54), (0.02,0.53),$
$(0.05,0.91), (0.08,0.90), (0.05,0.95)]$

and

$\breve{W}(pcrs)_j = [\underline{w}(pcrs)_j, \overline{w}(pcrs)_j]$
$= [(0.01,0.57), (0.34,0.66), (0.07,0.87), (0.02,0.59), (0.0.03,0.71), (0.04,0.73), (0.04,0.84),$
$(0.05,0.80), (0.03,0.646), (0.04,0.89), (0.06,0.80), (0.02,0.52), (0.02,0.48),$
$(0.05,0.90), (0.09,0.80), (0.06,0.96)]$

The final results for GSDPs by the proposed model and two fuzzy decision methods are reported in Tables V and VI.

TABLE V. Values of the indices and ranking of GSDPs by the proposed approach

Green Supplier Development Programs	Γ_i	K_i	Z_i	Sc_i	Ranking Order
P₁	0.5273	0.8497	0.8148	0.6493	1
P₂	0.4546	0.8455	0.8029	0.6024	3
P₃	0.5494	0.8141	0.7804	0.6486	2

TABLE VI. GSDPs ranking by presented approach and two fuzzy decision methods

Green Supplier Development Programs	Sc_i	Ranking Order of the Proposed Model	Final Scores by Awasthi & Kannan (2016) Method	Final Ranking Order by Awasthi & Kannan (2016) Method	Final Scores by Ye and Li (2014) Method	Final Ranking Order by Ye and Li (2014) Method
P_1	0.6493	1	0.186	1	0.715	1
P_2	0.6024	3	1.000	3	0.676	3
P_3	0.6486	2	0.332	2	0.704	2

The presented approach is confirmed by the two fuzzy decision methods in practice by the GSDPs of this case study.

V. CONCLUSION

The approach proposed in this paper was significantly helpful by introducing a new decision framework under uncertainty. Supply chain managers were able to successfully structure their decisions and to provide weights of their green supplier development programs (GSDPs). The assessment and selection could assist resource and investments allocations. Another essential managerial ramification was that outcomes could be different depending on the real application. A careful analysis of the competitive and organizational contexts should be carried out by supply chain managers who wanted to apply the proposed model. The decision modelling was able to regard uncertainties, and users of the proposed model had to know the additional uncertainties posed by the elements that should be incorporated as well as managerial perceptions related to the factors and their relationships. In this paper, by considering IVFSs and PSCs, we presented a new assessment procedure for GSDPs. The PSCs and IVFSs included and coordinated uncertainties related to assessing suppliers' GSDPs involvement propensity. A new group decision approach by IVFSs was introduced along with a TOPSIS method and PM, PSD, and PCRS-matrices. In addition, a new version of the entropy method was developed to handle weights of appraisement factors with PSCs. Furthermore, a new closeness coefficient of alternative indices was presented to choose the GSDPs. Finally, the validity of the proposed model was studied by an application example in India taken from the recent literature. The approach could be regarded as an important decision support tool for logistics managers. For further research, a more careful relationship analysis to provide influences of GSDPs on each other and various projects can be carried out.

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